HARD X-RAY AND WIDE FOCUSING TELESCOPES

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Principal Investigator
Dr. Paul Gorenstein

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Wallops Island, VA 23337

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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The NASA Technical Officer for this grant is William B. Johnson, Code 810.0, NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA 23337.

1 Introduction

The subjects of this program are the development of two new types of X-ray telescopes, the wide field telescope, and the hard X-ray telescope.

2 Wide Field Telescope

The wide field X-ray telescope is based upon the lobster eye geometry which has been described in the literature and in annual and final reports of grants of the PI which have preceded the current one. Its principal applications are continuos monitoring of time variations occurring in many sources distributed over a large part of the sky and performing a wide X-ray survey with high sensitivity and large photon collection for spectroscopy. The wide field telescope studies are being carried out in collaboration with colleagues at the Czech Technical University and the Astronomical Institute in the Czech Republic. During the past year Czech colleagues built small scale two dimensional lobster eye cells by electroforming. In principal these telescope cells can be arrayed over a complete sphere that views the entire sky all the time. This telescope resolves all the sources from each other.

SAO did not construct any more wide field prototypes. Our effort was confined to analytic studies and simulations of a device that would be part of a multi-instrument MIDEX payload devoted to the study of gamma ray bursts. However, with most of the payload capacity taken up by other instruments our studies showed that a lobster eye telescope system which met our requirements would be too large and too massive for the remaining capacity. Therefore, it was included in a proposal that was presented to NASA in response to a call for MIDEX experiments.

Constructing a lobster eye telescope in the Kirkpatrick-Baez like geometry (orthogonal stacks of linear reflectors arrayed along radial lines of a cylinder) described by Wolfgang Schmidt of MPI (Germany) in 1975 is relatively straight forward. A telescope made by us was described in a previous report. However, the detector is a substantial problem. Its surface is a segment of a sphere with half the radius of the sphere of the telescope surface. For example, for a lobster eye mirror that is a hemisphere with a radius of 1m the physical area of the detector is 1.6 m^2. Furthermore it must be position sensitive. The ideal detector would be an array of X-ray CCDs. However 1.6 m^2 of X-ray CCDs would be incredibly large. We performed literature searches for newer technology and less costly solid state devices. The CMOS active pixel sensor seems to be promising but still not up to the requirements.

3 Higher Resolution Telescopes

SAO and the Brera Observatory (OAB) are engaged in a program to produce a version of HXT with multilayer coatings that offers higher angular resolution than other approaches described in the literature. The process builds upon the whole shell electroforming technology that was developed for BeppoSAX, JET-X, and XMM. The mirrors for JET-X and XMM achieved better than 20" (HPD) angular resolution. Based upon estimates of the total cosmic ray induced background above 20 keV in all CZT detectors (Armstrong, Colborn, and Ramsey, Report to HXT group, 1999) it appears that the faint source detection sensitvity of HXT exposures exceeding 10^4 seconds will be background limited. In those measurements sensitivity is inversely proportional to the HPD. Therefore a 20" telescope has three times the detection sensitivity of a 1' telescope. In addition improved angular resolution is useful for imaging extended sources like SNRs and resolving source dense regions in neighbor galaxies and stellar clusters.

There are new obstacles to overcome in adapting the electroforming process to higher energy telescopes with multilayer coatings. A separation agent is needed that results in a smoother replica surface for the multilayer coatings than does the SAX/JET-X/XMM evaporated gold. Methods also needed for applying multilayer coatings to the inside surface of whole double conical replica shells, and reducing the mass of the shells by making them thinner than before. We hope to accomplish the last without compromise to the angular resolution by utilizing novel alloys with more strength being developed at several places.

Currently single conical 28 cm diameter mandrels are being fabricated by SAO and OAB (Fig 1). The aluminum base mandrel is scheduled to be polished at OAB this summer after it is coated with a layer of electroless nickel. The electroforming will be done at OAB. The HXT mandrels will be have to be polished more finely than SAX/JET-X/XMM mandrels to accommodate the multilayers. To permit that we devoted some time to examining several electroless nickel products to identify ones which are can be polished to 2-3 A rms. In addition there is an effort to find a separation agent with a smoother surface than the SAX/JET-X/XMM evaporated gold. Some promising results for sputtered carbon as a separation agent were reported at last years SPIE meeting (Romaine et al. 1998 SPIE 3444, 565). However, the effectiveness of carbon is system dependent in a way that is not yet understood. More trials are being performed on carbon and other materials.

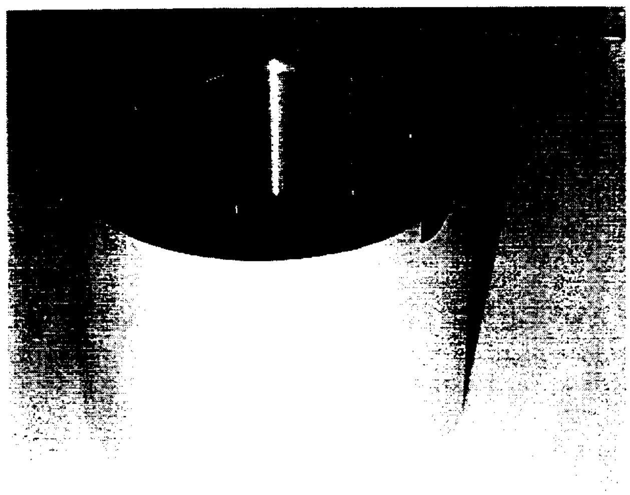

Figure 1: 28 cm diameter conical mandrel for use in electroforming studies

The final hurdle to surmount is applying multilayer coatings to the interior of the conical shells. Two approaches are being studied. SAO's versatile DC magnetron sputtering system is depositing multilayer coatings directly upon the interior surface of the shells (see below). OAB is experimenting with transferring entire multilayer coatings from a mandrel to the replica. These results are being presented at this meeting (SPIE Proc. 3766, Citterio et al.). Both have been successful. It is possible that the former process will be more effective or less costly for larger diameter shells and the latter for small diameters.

4 Multilayer Optics

SAO has completed construction of two vacuum chambers designed to use DC magnetron sputtering to fabricate multilayer films for hard X-ray optics. The first chamber (figure 2a) was designed as a quick turn around chamber for coating small (3inch) flat substrates for testing different material combinations and fabricating different multilayer structures for testing at higher energies. Several different multilayer films (and material combinations) grown in this chamber have been characterized and the results are being presented at this meeting (SPIE 3773-12, Ivan et al.). The second chamber (figure 2b) was designed to deposit multilayers on both the inside surface of integral optics and onto the curved surface of segmented optics. Several different materials and multilayer combinations have been deposited in this chamber onto flat substrates (silicon wafers and float glass) and also onto curved substrates (duran glass cylinders and slumped glass). Figure 3 shows two Duran glass substrates (coated and uncoated) and also includes a plot of the 8keV reflectivity data for the constant d-spaced multilayer. This is the first report of a multilayer stack being deposited onto an integral optic. Similarly, figure 4 shows one of the coated slumped glass substrates along with the 8keV reflectivity data for a constant d-spaced multilayer coating. Graded d-spaced multilayers have also been deposited on a Duran substrate and on slumped glass substrates as well as flat substrates. This data is now being analyzed.

Figure 2: Figure on the left (1a) shows the small chamber built for quick turnaround testing of different material combinations; figure on the right (1b) was built to coat the interior of integral optics.

5 Effective Area Estimates

A limited study of HXT's effective area was carried out by Christensen and Gorenstein for a 10m focal length double conical telescopes with different multilayer coatings in three ranges of radii (effectively three ranges of graze angle). In as much as coating all the HXT substrates within a reasonably short time will require several deposition facilities to operate simultaneously there is little disadvantage to their depositing different materials. The potential gain is increasing the effective area and/or reducing the amount of material required and consequently, the fabrication time. In addition W/Si multilayers coatings not only have higher reflectivity than Ni/C but are also deposited more easily. However, the reflectivity of W ends abruptly at its 70 keV K edge whereas there is value to extending the bandwidth. Reflectors coated with lighter metals like Ni and Mo whose reflectivity has recovered by 70 keV when situated at low graze angles can add to the bandwidth. Fig 2 is a sample calculation showing the theoretical effective area of the HXT mirrors with favorable assumptions for the interface roughness for three different coating perscriptions. The solid line

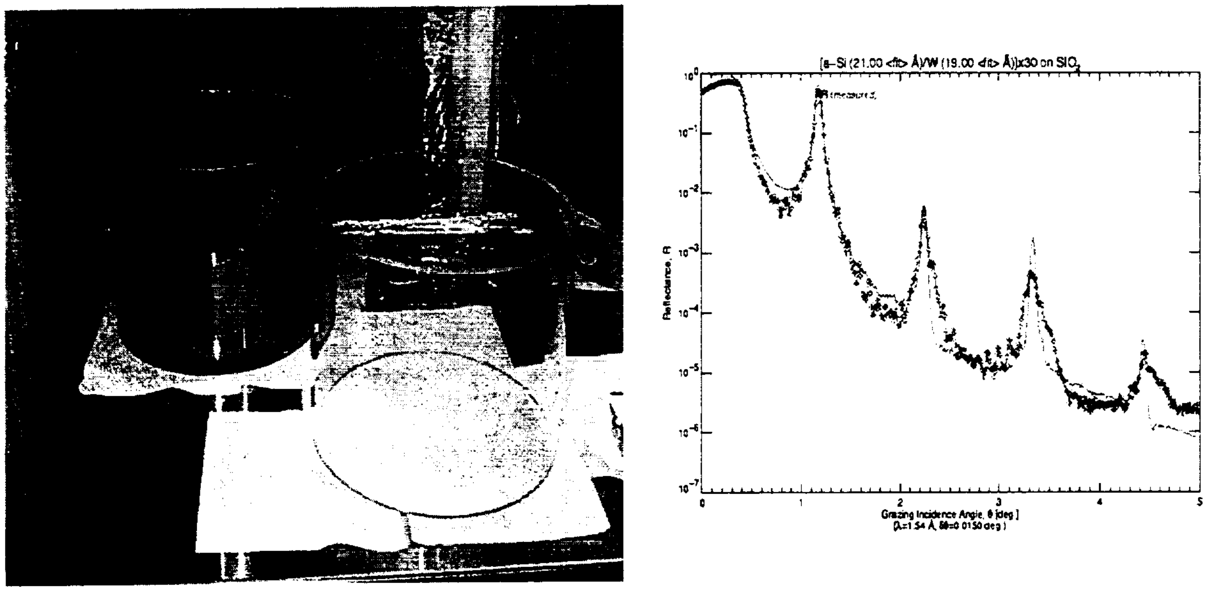

Figure 3: Photo shows coated and uncoated 10.5 inch diameter Duran glass substrates used for testing. Plot is 8 keV reflectivity data (points) for the optic shown here along with fit to the data (solid line) using the following parameters: N=30 bilayers W/Si, d=40.0, gamma=0.475, $\sigma_{W/S} = 3.5$ $\mathring{A}$, $\sigma_{S/W} = 5.0$ $\mathring{A}$

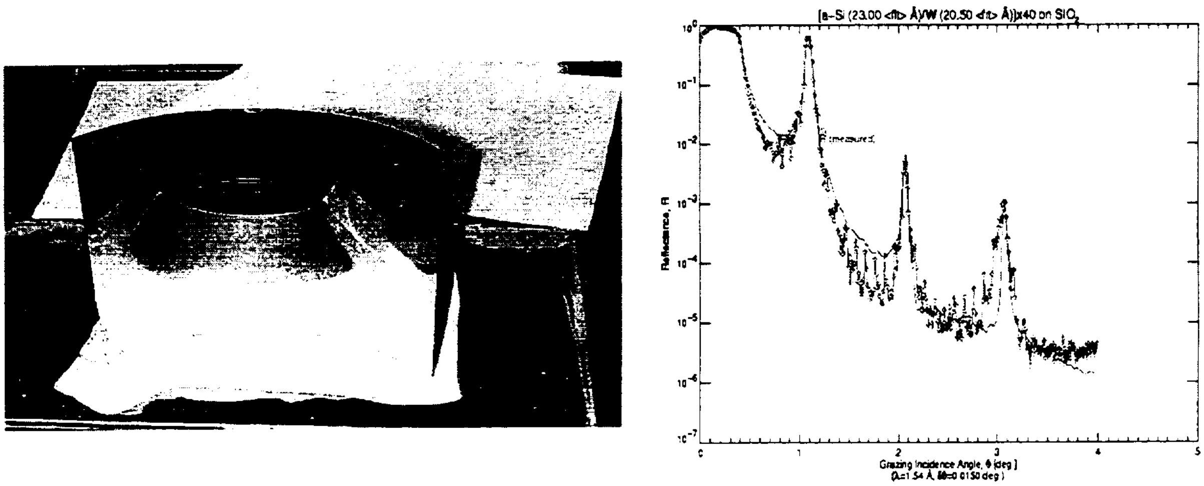

Figure 4: Photo shows coated slumped glass substrate along with plot of 8 keV reflectivity data (points) for this optic and model fit (solid line) using the parameters: N=40 bilayers W/Si, d=43.5, gamma=0.471, $\sigma_{W/S} = 4.5$ $\mathring{A}$, $\sigma_{S/W} = 6.0$ $\mathring{A}$; the substrate was slumped to a 4 inch radius.

represents telescopes where all substrates are coated with W/Si, the dashed line with Ni/C, and the dash-dot line, inner shells are coated with Cu/Si and the other shells with W/Si. The W/Si + Cu/Si telescope has the most area above 70 kev and the area below 70 keV is acceptable.

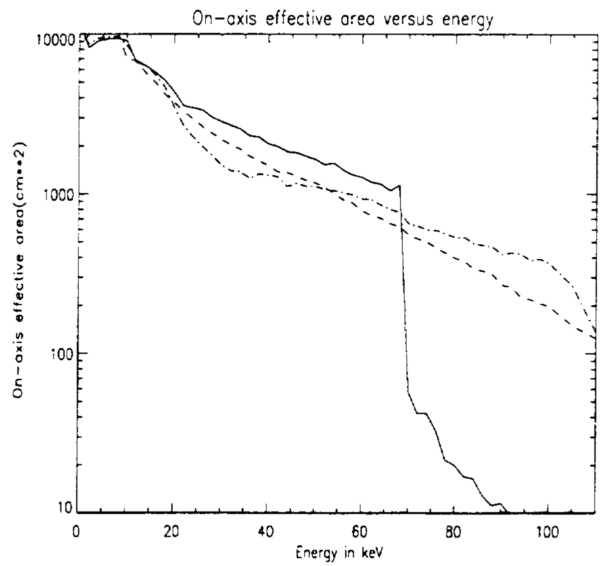

Figure 5: Effective area vs. energy for different coatings: solid line represents W/Si coatings, dashed line Ni/C and dashed dot line Cu/Si on inner shells with W/Si on outer shells.